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Robot Manipulation Using Electro-Magnetic Levitation System

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Abstract

In a large class of industrial robot manipulators, its end effector for suporting the moveing object have designed with mechanical suspension method(gripper).

In this paper, We descrive a high performance magnetically levitated end effector of robot, where is no mechanical contact and friction.

1 Introduction

A proto type end effector has been build using D.C.electro-magnet coil with photo-sensor and controlled by analog PID loop electronic circuits.[3]

The exciting current of magnet coil is controlled by PWM-chopper circuit using power FET in ca. 15khz of chopper freqency.

The magnetic air gap is hold at constant value 4 mm by feed back controll of photo-sensors signal.

The moveing object is a magnetic steel ball and its, diameter 25mm, weight 67g.

We examine the manipulation to float a magnetic ball using a five degree of freedom robot and a TV-camera type position sensor.

The magnetic air gap is chosen 4 mm enough to manipulating motion through a limited range of positions and speeds.

For the prevention of mechanical contact, we have installed a another photo-sensor, in crosswise to the air gap sensor, that is the combination of a LED and a photo-transister.[4]

These dynamic characteristics are designed using the simulation software "Matlab" for wide range of manipulating conditions.

The TV-camera can being recognized the ball position and the robot is controlled by computing program to manipulate the ball at picking point, and traverse to goal placing position.

We have good results at the normal speed in pick and place works for industry use of this floating suspension system.

These contact-less manipulator system will be required in the production line of VLSI, as like of vacuum compatible wafer handling robot.

2 Electro-Magnetic Levitation System

A block diagram of robot manipulation using electro-magnetic levitation system is shown in figure 1.

The exciting current of magnet coil is controlled by MOS type FET with PID controller and PWM type chopper circuit.

The air gap of the object is detected by photo-sensor,which is combined by a photo-transister and a LED and referred to 4 mm.

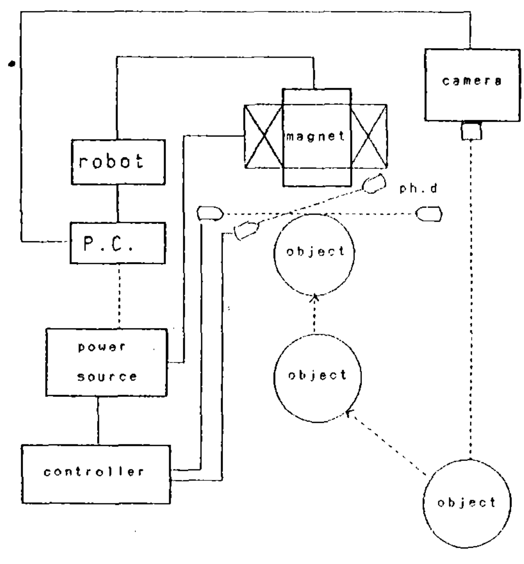


Figure 1. The brock diagram of robot manipulation using electro-magnetic levitation system

3 System Modeling

The system model to study the electro-magnetic suspension system shown below.[5]

An electro-magnet consisting of N turns of wire around a highly permeable magnetic core is being used to suspend an payload of mass m.

The mass is sepatated from the magnet by a distance of x, hereafter referred to as "the air gap".

The coil current is denoted by i and the voltage at the coil terminals is e.

An electro-magnetic suspension system is shown in figure 2.

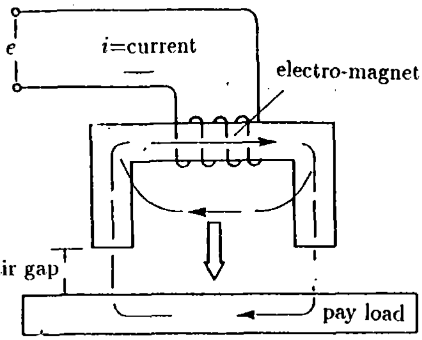


Figure 2. An electro-magnetic suspension system

3.1 Electrical/Magnetic Dynamics

Assuming that the permeability of the magnet and mass is much larger than air, we use the approximating conclusion that the magnetic field intensity is concentrated in the two air gaps.

If the wire of the coil has electrical resistance r, then the terminal voltage e, the coil current i, and the magnetic flux linkage λ are related by

$$e = ri + \frac{d\lambda}{dt} = ri + \frac{\mu_0 A N^2}{2}\left(\frac{1}{x}\frac{di}{dt} - \frac{i}{x^2}\frac{dx}{dt}\right) \qquad (1)$$

3.2 Mechanical/Magnetic Dynamics

The mechanical dynamics of the system in figure 2 are modeled by

$$m\ddot{x} = mg + f$$

where g is the gravitational constant and f is the force of electro-magnetic origin.

This force can be determined from the magnetic co-enegy and electro-magnetic origin.

In summatry, the complete mechanical dynamic equations for the electro-magnetic suspension systems are

$$m\ddot{x} = mg - \frac{\mu_0 A N^2}{4}\left(\frac{i}{x}\right)^2 \qquad (2)$$

To derive a state variable description of the system, let us chose the following state assignment,

$$y = [y_1 \ \ y_2 \ \ y_3]^T = [x \ \ \dot{x} \ \ i]^T$$

Then,the nonlinear state variable model of the system is described by the following equations

$$\dot{y}_1 = y_2 \qquad (3)$$

$$\dot{y}_2 = g - k_1 y_1^{-2} y_3^2 \qquad (4)$$

$$\dot{y}_3 = y_1^{-1} y_2 y_3 - k_2 y_1 y_3 + k_3 y_1 u \qquad (5)$$

where

$$k_1 = \frac{\mu_0 A N^2}{4m} \qquad (6)$$

$$k_2 = \frac{2r}{\mu_0 A N^2} \qquad (7)$$

$$k_3 = \frac{2}{\mu_0 A N^2} \qquad (8)$$

3.3 Linear Approximate Models

As we stated earlier, many approaches which are used to analyze and compensate the electro-magnetic levitation system are based upon linear approximations of the nonlinear model (1) or (2).

If one assumes that a current sourece i will be the excitation to the system, then a second order transfer function can be found to model the dynamics.

Equation (5) is simply omitted from the state model and the variable y_3 is treated as the model input. Alternatively, we may omit equation (1) and retain the second order model of equation(2).

In either case, one can easily show that equilibrium point of the reduced order model satisfies the condition.

$$i_0 = \sqrt{g/k_1} \cdot x_0$$

wher x_0 is the nominal air gap distance. The second order transfer function that results from linearization about the nominal operating condition($x = x_0, i = i_0$) is given by

$$\frac{X(s)}{I(s)} = -\frac{(2/x_0)\cdot\sqrt{gk_1}}{S^2 - (2g/x_0)}$$

The linearized model indicates that the equilibrium point is unstable.

If the excitation for the system is the terminal voltage e, then the equilibrium point($x = x_0, x = 0, e = e_0$) statisfies the condition

$$e_0 = k_2/k_3\sqrt{g/k_1} \cdot x_0$$

An approximate, third order transfer function that describes the plant dynamics near the equilibrium point is

$$\frac{X(s)}{E(s)} = -\frac{2k_3\sqrt{gk_1}}{(s + k_2 x_0)(s^2 - 2g/x_0)} \qquad (9)$$

The first order term in the denominator is associated with the electrical dynamics, the coefficient $k_2 x_0$ is equivalent to the ratio of resistance to nominal inductance, $r/L(x_0)$.

4 Simulation Results using "Matlab"

These system model is simulated by using "Matlab".

A number of different approaches can be used to design compensators. Application of classical root locus technique shows that a PID compensator is very useful. The parameters for second order model are g=67(gravitation constant). In figure 3 the simulated response of this levitation system is shown.

The air gap distance changes from the initial value to the referense value with vibrative condition.

In figure 4 and figure 5, the simulated response of other levitation parameter are shown.(g=28,g=130)

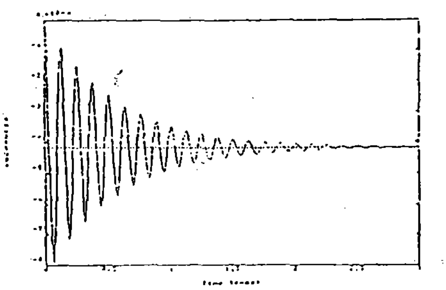


Figure 3. Simulation result of a step response (g=67)

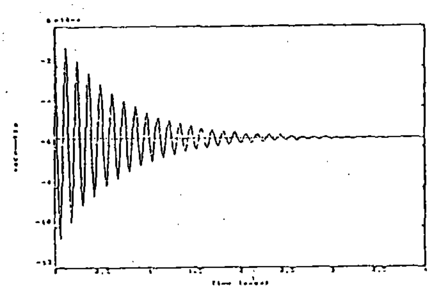


Figure 4. Simulation result of a step response (g=28)

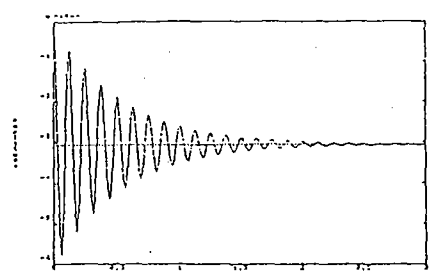


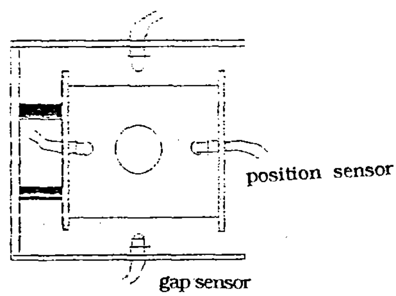
Figure 5. Simulation result of a step response (g=130)

5 Photo-Sensor

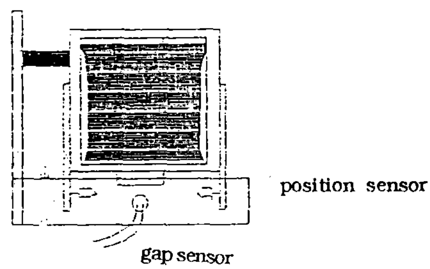
For a given postition, the LED light beams on the lateral cells are installed at the D.C.magnet.

Figure 6 (a),(b)shown the configuration of these photo-sensor. One pair of photo-sensor acts to detect the air gap and another pair acts to start the exitation of magnet coil. This air gap is about 3mm(smaller than 4mm).

In figure 7 the sequence of the relative position of ball and sensor at float and place motion are shown.



(a) Up side view



(b) Side view

Figure 6. Configuration of photo-sensor

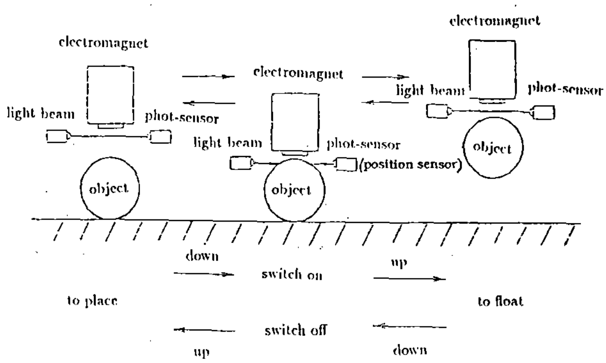


Figure 7. Sequence of the relative position of ball and photo-sensor

6 Control Experiment

A very general feed-back control circuit for the magnetic levitation system is shown in figure 8.

We examine the manipulation of a magnetic steel ball using a robot with this magnetic levitation system.

We used the TV-camera for the purpose to recognize the position of moving object.

This TV-camera is "X-Y tracker", that can recognize the digital position data at X-Y axis in real time.

In figure 9 (a),(b) the search ares of X-Y tracker and digital coordinates are shown, and it is connected to the computer and robot controller.

The robot moved to picking point of ball by computing program from this camera signals and then robot levitated a ball and traversed to the goal placing position.

We have good results at the normal speed in pick and place works using this magnetic levitation system.

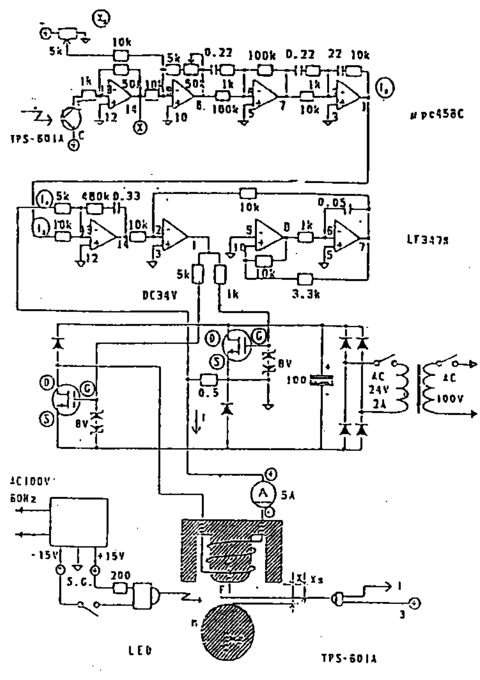
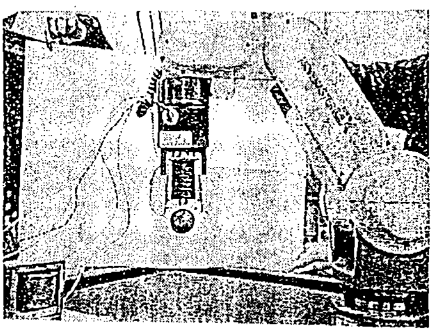
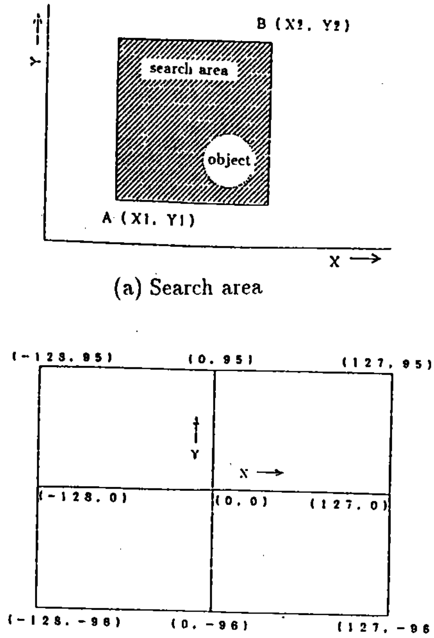


Figure 8. A circuit for the magnetic levitation system



Phot. 1. Proto type of robot manipulation experiment



(a) Search area

(b) Digital domain

Figure 9. The search area and digital coordinates of "X-Y tracker"

7 Conclusion

We have discussed some of the difficultis inherent in contact-less manipulation using magnetic levitation.

In the case of pick up motion, end-effector approches to the object with no excitating current of magnet, and excitation must start at inner air gap rang.

A proto-type magnet, including power drive amplifiers and sensing electronic has been build, and controlled to float with extremely encourging result.

We expect that the contact-less manipulation described here, with friction-less magnetic suspension, will find many application in automatic assembly and testing for microelectronics.

References

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